SCIENCE

FRIDAY, FEBRUARY 14, 1913

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PLEISTOCENE GEOLOGY OF NEW YORK STATE.[1] *I*

INTRODUCTION

THE primacy of New York among the states in population, wealth, manufacture and commerce is based on its physical characters—geologic structure, physiographic relief and geographic relations. The state has the greatest range and perfection in its stratigraphic series and the greatest variety in physiographic features. In scenery other states may possess single features of surpassing grandeur and beauty, like the Colorado Grand Canyon, Yosemite Valley, Crater Lake, the mountains of the Cordillera or the snow-capped volcanic cones of the northwest, but for abundance and variety of beautiful scenery of educational value New York may claim first place. In the variety and excellence of Pleistocene phenomena the state probably excels any other equal area of the earth's surface. This is due to the varied and unusual physiography combined with a favoring attitude of the area in relation to the continental glacier. The features of special excellence occur largely in the western part of the state. These are the series of more than twenty parallel, north-sloping valleys which hold the unique series of twelve so-called Finger lakes; the remarkable succession of glacial lakes in the Ontario drainage area; the conspicuous, abandoned channels of the rivers that drained those lakes; the surpassing display of drumlins, of kames and eskers; the fine series of mo-

[1] Annual address of the president of the Geological Society of America, read on December 28, 1912. The numerous maps which illustrated this address are here omitted.

raines, and the large number of Postglacial ravines.

The purpose of this writing is to utilize this remarkable display of Pleistocene phenomena in illustration of the glacial history and in brief discussion of some problems in the philosophy of glaciation.

MULTIPLE GLACIATION

The accepted facts of multiple glaciation in the Mississippi basin coupled with proofs of Prewisconsin drift in Pennsylvania and New Jersey and on Long Island, with accumulating evidences in New England, demands the theoretical acceptance of at least dual glaciation for New York state. But the positive proof, in the field, of a Prewisconsin ice sheet has not been found. In several localities the deeper till is so unlike the upper till that it strongly suggests a separate origin. Some singular topographic features are not satisfactorily explained without appeal to the earlier ice invasions. The Rutland Hollow, east of Watertown, is an example. Many erosion features, specially in the St. Lawrence district, seem inconsonant with the work of the latest ice.[2] However, we have found no example of interglacial or warm-climate deposits interbedded in the till. Such should be expected and sought, but at present we can only say that multiple glaciation in New York, at least north of Long Island, is quite certain in our philosophy but that it remains unproven in observation.

Although our glacial phenomena in New York are doubtless not the effects of merely the latest or Laurentian ice sheet, the latter so strongly dominates that for purpose of this writing it is impracticable to attempt discrimination, and unless specially noted it will be understood that reference is to the latest, or Wisconsin, glaciation.

[2] For discussion of this subject see N. Y. State Museum Bulletins, No. 145, pp. 164–172; No. 160, pp. 17–18.

LAURENTIAN (LABRADORIAN) ICE BODY

The reach or extent of the latest ice sheet has long been known in a general way through the early work of Upham, Lewis and Wright in tracing the terminal moraine. In later years the stretches of the terminal moraine which lie in New York have been reexamined, on Long Island by Woodworth and Fuller and Veatch, and in Cattaraugus county by Leverett. There are two small areas in the state which the ice sheet did not cover, the south side of Long Island and the district partly enclosed by the northward bend of the Alleghany River.

At its maximum the ice sheet covered the highest points in the state, the Adirondack (5,344 feet) and the Catskill (4,205 feet) mountains. Judging from the Antarctic and Greenland ice caps the surface of the Laurentian shield was a low dome of fairly uniform curvature, uninfluenced by the irregularities of the submerged land surface. Our only means of estimating the thickness of the ice cap is by assuming a gradient of the surface slope, as suggested by observations on the existing polar ice fields. Such data, however, can be safely used only in a suggestive way when applied to the Laurentian ice shield, because the difference in latitude must be an important factor. The border of our ice field, in latitude 41 to 44 degrees, was subjected to so much greater solar radiation and consequent higher temperatures, with heavy precipitation and rains, that it must have had increased plasticity and resultant mobility, giving the surface slope diminished gradient. But on the other hand the snow supply over the central area or alimentation ground of the ice field must have been greater than over the polar fields, which might give greater depth and steeper gradients toward the interior of the field. The anticyclonic winds over the ice cap, re-

cently emphasized by Hobbs, would brush the snow toward the borders of the field and so tend to reduce the surface slope of the interior.

Shackelton found that the great outlet glacier in Antarctica, named the Beardmore, had a rise of 80 feet per mile for 100 miles, with declining rate inland, attaining about 11,000 feet in 275 miles, or 40 feet per mile for the entire distance. If we assume a slope of 60 feet per mile for the glacier surface over western New York it gives an altitude of over 9,000 feet on the area of Lake Ontario, the margin of the ice sheet lying at near 2,000 feet altitude. Over central New York (district of Oneida Lake) the altitude would be about the same; and if to this we add 30 feet per mile to the middle of the Adirondacks it gives 3,000 feet more, or over 12,000 feet altitude. If we assume 40 feet per mile on the Hudson-Champlain meridian it gives 12,500 feet of ice on the Canadian boundary. Thirty feet per mile gives over 9,000 feet of ice. These figures may be somewhat excessive, but they at least prove the fact of a great thickness of solid water piled over the state. The effect of such weight will be noted later.

The ice mass had a spreading or radial flow, as a plastic body, due to its own weight. The prevailing direction over New York was southwestward, except that in the lower Hudson Valley the flow was southward, conforming to the valley. The waning or thinning ice sheet was deflected by the larger topographic relief, and when the ice mass resting over the Ontario basin ceased to be impelled by thrust from the northeast it developed a spreading flow, radiating from the area now occupied by Lake Ontario. This is well shown by the orientation of the drumlins in the Ontario basin. A good illustration of valley diversion is shown in the maps, depicting how the Hudson lobe and the Ontario lobe pushed into the Mohawk Valley from opposite directions, impounding glacial waters between them. As the direction of flow near the margin of the ice sheet must incline to right angle, or normal to the ice front, the direction of latest movement in any district can be approximately known if the ice limit is determined. The series of maps accompanying this writing show several stages in the waning and disappearance of the ice and suggest the direction of flow at different positions.

The set of maps gives fifteen positions of the ice front during its recession across the state. A larger number could be depicted, but only those have been selected which have some significance in the lake and drainage history. The criteria used in locating the ice front positions are the moraines and the ice-border river channels, the latter correlating with lake levels and shore features.

The recession of the ice front was certainly not steady or continuous, but must have had considerable oscillation, readvances and reretreats. The heavier belts of moraine and the lines of long-lived ice-border drainage probably represent readvanced positions.

The length of time represented by the passage of the ice front across New York is unknown, but is certainly scores of thousands of years. Probably 100,000 years is not too long. We may not judge the rate of waning by the present behavior of the ice fronts in Greenland and Antarctica, as the climatic factors due to difference of latitude must have been effective. If the oscillations of the ice front were due to any irregular or nonperiodic variations of climate, then we can have no idea of the time involved either in the advance or the waning of the ice sheet. And the only periodicity in climatic factors now recognized

that seems adequate is the precession of the equinoxes, having a variable but average period of about 21,000 years. Taylor has studied the Cincinnati-Mackinac moraine series from this viewpoint, and concludes that the fifteen rather equally spaced moraines represent 75,000 to 150,000 years, using the minimum length of the precession period.[3] The eight or ten morainic belts which we now recognize in western New York may correlate with that many on the Cincinnati-Mackinac meridian, but the recession of the ice front on the Hudson-Champlain meridian probably represents a much longer time than the Ohio-Michigan series.

If the changes in geologic climates be due to variation in solar radiation it is conceivable that some minor secularity might be responsible for the oscillations of the ice front. Variation in the amount of carbon dioxide content of the atmosphere can more reasonably be invoked to explain the larger and more irregular changes in ancient climates than for the shorter and more regular changes that caused the ice front oscillations. The same is true of continental elevation as a cause of colder climate.

GEOLOGIC EFFECTS OF THE ICE SHEET

Erosional work.—The subject relating to glaciers that has been the cause of the greatest difference of opinion is the erosive power or destructional work. The writer will here not discuss seriously glacial erosion in general, but only so far as it applies to New York.[4]

That mountain glaciers abrade their valleys and by moderate erosional work change the V-shape to the U-shape has long been apparent. The destructive work at the head of the glacier in production of cirques is fully recognized, although this is largely atmospheric effect. All argument for deep erosion by glaciers based on the abrasional or plucking action of mountain or stream glaciers fails when applied to New York, as there were no effective mountain glaciers in New England and New York, at least not during the waning of the Laurentian ice body. The ice disappeared from the more elevated tracts, while lingering in the lowlands. Whatever the erosive power attributed to mountain glaciers of Norway or New Zealand, it can not be invoked here, as New York had no such glaciers. We have to consider only the work of a continental glacier. Whatever destructive effects an ice cap may have under its central or subcentral mass, it has long been admitted that it is not a vigorous erosive agent in its border zone or dissipating belt. The district in New York, the Finger Lake area, which has been used in illustration of glacial valley erosion, was always in merely the outer zone, or that of predominant deposition by the Laurentian glacier. All students of New York geology practically agree on the lack of vigorous ice erosion over all the rest of the state. Those who have worked in the Adirondacks and in the Champlain and St. Lawrence valleys have noted the proofs of a weak erosion.[5] It has been shown by Gilbert and the writer that erosion was weak on the Ontario lowland of western New York. The claim for deep erosion has been only for the valleys of the Finger lakes, specially Cayuga and Seneca, the claim based chiefly on anomalous topographic features.

The advocates of glacial deepening of the valleys appeal either to vigorous currents at the bottom of the ice sheet or to the tongue-like lobations of the ice front, to deeply gouge the bottoms of the valleys so as to produce hanging side valleys and

[3] *Journal of Geology,* Vol. 5, pp. 421–465, 1897.

[4] For the argument in general see *Bull. Geol. Soc. Am.,* Vol. 16, pp. 13–74, 1905.

[5] See N. Y. State Museum Bull. 145, pp. 147, 171–172, 1910.

"oversteepening" of the lower slopes of the main valleys. The existence of effective basal currents in the region under consideration seems highly improbable. The general land slope was opposed to the ice flow, that is, the ice was moving on an upslope. The lower or basal ice was very heavily burdened with rock rubbish and would naturally serve as the bridge over which the upper ice traveled, partly by shearing and partly by superior plasticity. But if for argument we grant the existence of effective bottom currents, then we are forced to concede that under the conditions of great vertical pressure, with the movement on an up-slope in soft shale rocks, the erosion would have to be by abrasion and not by plucking. At its intensest, abrasion must be a slow and a self-checking process. Long ago Russell emphasized the fact that plasticity of the ice is reduced in proportion to its burden of drift. Admitting this, it follows that an excess of rock stuff in the basal ice, the inevitable result of heavy erosion, would produce stagnation. Moreover, the excessive product of grinding would serve as a buffer to protect the bed rock, just as a stream full-loaded with detritus ceases to erode.

If the lobations or valley tongues of the ice margin had any erosive effect comparable to mountain glaciers, such work should have been greatest south of the land divide, or where gravity directly assisted the flow. But the conspicuous lack of erosive work on the uplands and south of the divide is frankly admitted. In description of the area covering the eight quadrangles of the Watkins-Ithaca-Elmira-Owego district, in the U. S. Geological Survey Folio 169, Professor Tarr, who was the leading advocate of glacial erosion of the Finger Lake valleys, wrote:

> In harmony with this evidence of slight erosion is the fact that the mature upland divide areas have suffered notable modification only by deposition and not at all, so far as can be seen, by ice erosion (page 16).
>
> In the southern half of the area glacial erosion was not sufficient to remove the products of preglacial decay from the hills, nor, so far as any evidence goes to show, to modify perceptibly the topography even of the valleys (page 31).

North of the divide the lobations of the ice front were pushed up the valleys by the pressure of the ice in their rear, and were so heavily loaded with drift that they were not eroding, but depositing. The fact of superload of drift is clearly shown by Tarr's map of the surficial geology. South of the divide morainal drift is almost entirely lacking in the south-leading valleys and only scantily represented in the larger east and west Susquehanna and Chemung valleys. Tarr says:

> On the upland, south of the area of the recessional moraines, little moraine material is found and no definite system has been worked out.
>
> The complex of moraines in the northern part of the Watkins Glen quadrangle and the northwestern part of the Catatonk quadrangle, contrasted with the general absence of moraines in the southern half of the area, forms one of the most striking features of the Quaternary geology (page 17).

The heavy morainal drift in the valleys north of the divide was not derived from erosion of those valleys, but was the accumulated rock rubbish acquired by the lower part of the ice sheet during its entire journey across the state. When the ice was thick enough to override the divide and flow south it was the superficial, drift-free ice that passed across, while the lower, drift-loaded and relatively stagnant ice reposed in the Ontario basin and its valleys, serving as the bridge that was overriden by the clearer and more plastic superficial layers. In evidence of this is the relative absence of drift south of the divide, and the almost entire absence of crystalline rocks or far-traveled material. Quoting Tarr:

In the uplands south of the recessional moraines foreign fragments are much more rare, and in some parts of the uplands a careful search is required to find even a small pebble of crystalline rock, while bowlders are practically absent (page 16).

To whatever extent the ice in the margin of the snow field was produced by the centrifugal, anticyclonic winds from the interior of the ice cap, as suggested by Hobbs from study of the existing continental glaciers,[6] it also favored lack of drift in the periphery of the ice body. With the waning and thinning of the ice cap the drift-loaded lower ice was finally uncovered so as to constitute the marginal belt, and was then subjected to thrust or push from the thicker body on the north. At this stage the heavy moraine deposits were made in the valleys, producing the present drainage divide, and the lobations of the ice front built the crescentic lateral-terminal ridges north of the divide. At a later stage of the waning, when the required factors were properly combined and balanced, the drumlins were constructed on the lowlands, northward.

Many facts are cited by Tarr showing the impotency of the latest ice sheet, and he finally admitted that the

Wisconsin ice sheet failed to notably modify the topography in the greater part of this area (page 16).

This would seem to terminate the debate about glacial erosion in the Finger Lake district. But it does not, as the responsibility for the anomalous topography is shifted back to the Prewisconsin glaciers.

This carries with it the necessity of believing in 1,500 feet of vertical erosion in the Seneca Valley by the continued ice work of at least two periods of glacial occupation, separated by an interval of gorge cutting several times as long as the postglacial interval (page 16).

The statement is warranted, therefore, that these valleys have been profoundly modified by glacial erosion, both by deepening and broadening (page 30).

But here, as in the process of glacial stream erosion, the bulk of the work was done by an earlier ice advance (page 31).

It is admitted that ice sheets may have some individuality and that successive sheets on the same territory may have somewhat different behavior and produce different effects, due to differences in the climatic, topographic and drift factors. But it does not seem reasonable that one ice sheet could deepen Seneca Valley 1,500 feet, while its successor did practically no eroding at all. If the Prewisconsin ice sheet had such remarkable excavating power it should have produced conspicuous erosional effects elsewhere than in the valleys, and specially in the southern part of the state, and should have piled heavy "old drift" deposits beyond the reach of the Wisconsin ice.

The drift burden of the Laurentian ice sheet is represented not merely by the mass of the moraines and the volume of detritus carried away by the glacial drainage, but also by the enormous bulk of drift built into the drumlins. Even if the drumlins were partly constructed by the earlier ice sheet they can not, because of their location, represent any product of deep erosion of the sections of Seneca and Cayuga valleys in question. There are no heavy moraine deposits south of the Valley-Heads moraine, for the terminal moraine is not massive, and the ancient drift in Pennsylvania and New Jersey is not excessive in volume. The only other disposal of the great volume of débris that should have been produced by deepening of the valleys 1,500 feet must have been by outwash of the glacial drainage. But when the valley-train and outwash deposits attributed to the latest ice are considered there is no

[6] "Characteristics of Existing Glaciers," 1911.

very large volume left to represent any earlier drainage.

The entire argument for deep ice erosion in the Finger Lake region is based on physiographic features, hanging valleys and "oversteepened" valley walls. The writer believes that sufficient attention has not been given to the effects of Prepleistocene drainage in connection with the climatic, topographic and diastrophic factors. The high elevation of the northern part of the continent in Tertiary time seems to be a fact, and accompanied by warm climate. If necessary to explain phenomena we may assume effective vertical movements in our region. The Tertiary was certainly a time of vigorous drainage and remarkable valley-cutting in northern lands. When the fiord valleys were making in other lands what was doing here? Undoubtedly our rivers were also active, and the deep valleys of central New York are one result.

At the last Baltimore meeting of the society the writer exhibited a series of maps suggesting the drainage evolution in New York.[7] The high "Hung-up" valleys with northeast by southwest direction, and mostly without present streams, seem to be an inheritance from the primitive drainage on the new land surface. The drainage lines of the upper tributaries to the Delaware and Susquehanna rivers preserve their original direction. During some Prepleistocene time the development of subsequent valleys along the strike of the thick and weak Ontario strata resulted in a great east and west valley, carrying a great trunk stream, the hypothetical Ontarian River. Into this valley was drawn from the south, as obsequent streams, all the drainage of western and central New York and the adjacent territory of northern Pennsylvania. The Susquehanna River turned northward at Elmira and occupied the Seneca Valley, which probably accounts for the excessive depth of the valley, a drilling at Watkins of 1,200 feet failing to reach rock. The Genesee River is the one stream which fully represents the Preglacial northward flow, having held to its northward direction clear across the state in spite of the tendency of glaciation to force it into southward flow. All the other drainage of south-central New York was forced to southward escape, mostly in tribute to the Susquehanna and through the new rock gorge at Towanda, Pa. A late and probably rapid land uplift, rejuvenating the obsequent drainage, will probably be found to satisfactorily account for the great depth and other anomalous features that have been used as arguments for deep glacial erosion in New York. Interglacial drainage may also be important in this work.

[7] Geol. Soc. Am., *Bull.*, Vol. 20, pp. 668–670, 1910.

It will now be understood that when the earliest ice sheet invaded New York it found a topography unlike the present, a remarkable series of parallel, deep, open, north-sloping valleys that headed southward, the larger ones in Pennsylvania. The present divides in the valleys are due to the moraine fillings left by the ice. The deep canyon-like valleys were occupied by the glacier and some abrasion and smoothing of the walls was inevitable. But it should not be forgotten that the ice tongues in these valleys were not mountain glaciers, but merely lobations of a drift-burdened margin of an ice sheet moving on an upslope. Conceding some erosive power to the ice tongues in the valley, then instead of deepening the valleys and oversteepening the walls and so producing the present convex cross-profiles they should have cut the walls and widened the valleys and produced concave profiles. In the work of stream glaciers convexity of valley slope is succeeded by concavity. In final word, to

a discussion already too long, in the opinion of the writer all the facts and philosophy of ice erosion argue against deep glacial erosion in the Finger Lake valleys.

One interesting product of glacial erosion is to be noted. These are some hills which have the form and attitude of true drumlins, but which are composed of soft shale, shaped into drumlin form. These rocdrumlins will be described later.

CONSTRUCTIONAL WORK.

Subglacial: Rocdrumlins.—The general drift sheet presents no special features meriting description at this time. The important subglacial deposits are the rocdrumlins. New York state probably has the best display of these interesting hills of any district in the world; in number, variety of form, variety in orientation, difference in composition and in the clear relationship to the correlating moraines.

Much space might be given to description of these singular and most beautiful hills, but they have already been quite fully described in a Bulletin of the State Museum.[8]

Possibly in other regions there may be drumlins produced by the ice overriding and reshaping moraines, but all the true drumlins observed in New York are certainly constructional in their origin. The New York moraines are mostly water-laid drift, especially north of the divide, the débris in the ice being largely grasped by the glacial drainage. If the drumlins were moraine accumulations they would have morainal composition and structure. On the contrary, they are very compact till, distinctly bedded with concentric structure. The best exhibition of the bedding is shown along the shore of Lake Ontario, between Sodus and Oswego, where the undercutting by the waves has dissected numerous drumlins from top to bottom and in different directions. Sand or gravel within the mass of the drumlin is of infrequent occurrence, though some of the drumlins between Clyde and Savannah hold considerable sand in their superficial layers. Many drumlins exhibit decided difference between the deeper and the superficial till, sometimes so pronounced as to suggest two epochs of construction.

[8] N. Y. State Museum Bull. 111, 1907.

Along the belt of outcrop of the soft Salina shales there are drumlins which have a shale base, and perhaps some with a shale core. Fifteen miles northwest of Syracuse and west of Baldwinsville the drumlin forms are entirely shale. The deeply weathered clay rock supplied to the ice sheet a plastic material similar in its behavior to the ground moraine. These hills are not true drumlins. They are wholly erosional in origin, as indeed are the true drumlins in their shaping. We have called them rocdrumlins, using the Celtic prefix. It is possible that similar forms will be found in the Champlain-Hudson Valley, shaped out of the softer Ordovician shales. The ice sheet does not appear to have had scraping force sufficient to shape into the drumlin curve any rock hills of harder materials than soft shale, though bosses of crystalline rocks in the St. Lawrence Valley and other districts of long-continued abrasion are rounded and smoothed on the struck sides.

The mechanics of drumlin construction is a complex problem. The required cooperation and balancing of several dynamic factors make the drumlins exceptional features even in the glaciated territory. The more important constructional factors appear to be: (1) An excessive amount of drift; (2) the drift of clayey or adhesive and plastic material; (3) such thickness of marginal ice and with such relation to the rearward ice body that the whole depth of

ice accepts a thrustal movement, producing a sliding motion of the ice in ground-contact; (4) such temperature or physical condition as to allow plasticity and some differential motion within the ice, essential for the overriding of the growing obstruction instead of its removal. Here is found a singular balancing of two opposing factors, rigidity and plasticity; rigidity holding the ice mass, as a whole, to its thrustal motion, while at the same time bands or currents within the ice sheet have unequal motion, permitting the curving or arching flow over the growing hill of drift. The drumlin-making process appears to be a plastering-on and a rubbing-down, depending on the condition of more friction between clay and clay than between clay and ice. The resulting form of the growing obstruction is that which offers the greatest resistance to removal, or the least resistance to the passage of the ice over it. The molding action of the ice sheet is well shown by the minor ridges in some districts, the secondary and tertiary inferior ridges lying on the flanks of or between the primary ridges suggest the wood-molding struck in the planing mill.

The complex of forces and conditions necessary for drumlin construction explains their peculiar distribution, orientation and form. In the western half of New York the rich display of drumlins (nearly a thousand ridges being shown by the contours on the Palmyra sheet alone) is practically limited to the territory north of the divide, where the drift was profuse and the thinning ice was pushing on an upslope. In the Ontario basin their attitude or direction of the major axis is radial to the middle of the basin, varying from due east to southwest. In the Erie basin a group about Chautauqua Lake points southeast, while in the Mohawk valley north of Richfield Springs a group has westward pointing. In the Champlain and Hudson valleys the drumlins point southward. In the St. Lawrence Valley they show the latest and spreading flow. Everywhere they show the later ice-flow direction.

The most typical drumlin form, that which seems to express the most vigorous action and effective balancing of the several factors, is an elongated oval with steep convex side slopes, and these are found in the middle of the drumlin belt. New York exhibits all possible variations from this form. The shorter ridges, sometimes approaching dome-shape, but usually with some irregularity or lack of symmetry, are found at the north or proximate side of the drumlin belt, which suggests that the broad form is the product of less perfect work. The much elongated and attenuated ridges lie at the south or ultimate side of the belt and indicate the more uniform or rigid flow of the ice sheet with deficiency of drift.

In the western end of the state the till sheet over large areas has been rubbed into a fluted or washboard form on a large scale, but with low relief. It is inferred that this drumlinized surface with ribs one fourth to one half mile wide represents the work of thick ice, having great weight and vertical pressure, with diminished plasticity and carrying only a moderate load of drift. The direction of the flutings, southwestward, is the direction of flow of the maximum ice body.

In central New York we have been able to definitely correlate the drumlin belt with its synchronous moraine; to determine the position of the ice front during the drumlin-making episode. On the meridian of Seneca and Cayuga lakes the drumlins of the north side of the belt are more scattering and irregular in form. In the middle of the belt they are close-set, typical, elongated ovals. Southward they become close-set ridges with secondary flutings; while at

the south edge of the belt they are slender ridges and flutings, too attenuated to be represented by the twenty-feet contours of the topographic sheets. It would require at least five-feet contours to show the frontal drumlinized surface. Two miles in front of the most southerly ridges indicated on the Geneva sheet lies a weak but definite moraine. It is weak because the ice had plastered its load of drift into the drumlins.

From the relation of the ice front to the glacial waters and other data it has been roughly estimated that the thickness of the ice over the middle of the drumlin belt was about 900 feet, or more than 700 feet over the tops of the highest drumlins.

Marginal: Moraines.—The only map published to the present time that shows moraines in detail is that by Tarr in the Watkins Glen-Catatonk folio (No. 169), which is accompanied by good description. This map, Surficial Geology, covers eight quadrangles of the south-central portion of the state and includes the upper (southern) ends of the Seneca and Cayuga valleys. Except a few fragmentary moraines in the east and west stretch of the Susquehanna and Chemung valleys there are almost no moraines south of the divide, as already noted in this writing. The lines of drift massing show decided lobation of the ice in the valleys north of the divide and conformity to the land surface. The plastic ice was here flowing on its own deposits and had no erosive power. Probably the only moraines in the state that can properly be called "lateral" lie in these valleys.

In the west half of the state the heavier or more conspicuous morainic belts have been approximately located though little precise mapping has been attempted. The most recent and definite is by Leverett,[9] and a sketch map, Fig. 11, page 15, in the Folio 169. These morainic belts clearly show the larger lobation of the waning ice sheet in the Ontario and Erie basins.

In the east half of the state the moraines have been located in only few places, excepting the terminal moraine. In the Hudson and Champlain valleys Woodworth has recognized some fragments and ice-contacts. This difference in moraine development between the two parts of the state is due to the difference in the gross topography. A glance at the map shows that on the Hudson-Champlain meridian the distance covered by the receding ice front is greater than in the Ontario basin, so spreading the drift over more area. The rocks in the east part of the state are more resistant to erosion, due to kind and structure. The Hudson ice lobe and its successor in the Champlain Valley were always faced by ocean waters and the terminal drift in the bottom section of the great valley was mostly scattered and buried under the water deposits. On the high grounds east and west of the marine inlet the surfaces are so rough, or even mountainous, that the moraine deposits lack continuity and volume. It will be very difficult to trace morainic belts across the Hudson-Champlain Valley with certainty, though it is important to know the lines of the receding ice front.

WORK OF GLACIAL WATERS

Erosional Work of Streams. Normal Drainage.—It is apparent that the flow of glacial waters freely away from the ice could occur only south of the divide, and as the present divide was established by morainal filling and lies north of the preglacial divide much of the southward flow was drainage of ice-dammed waters, and that some of the present south-leading channels were cut by the glacial waters. The preglacial flow of the main streams

[9] U. S. Geol. Surv., Monograph XLI., 1902.

was northward, but the tributaries had various directions. The glacial drainage took advantage of the favoring valleys and connected them into sequence of southward flow. Tarr thought that the work of stream diversion and of channel erosion was mainly Prewisconsin, for the district described in the Folio 169 (page 30). He specially cites the outlet of Cayuga Lake, the gorge of Tioughnioga creek and the gorge of Chemung River behind Hawes hill, west of Elmira. The copious waters from the waning Laurentian ice sheet were supplied with such volume of detritus that they were largely aggrading agents. It is possible that the south-leading valleys were mostly established by Prewisconsin glacial drainage and that the work of the latest glacial floods was chiefly transportative. In the eastern half of the state the glacial outflow was freely into the Susquehanna and Delaware escape or into the Hudson-Champlain marine inlet, so there was no necessity for cutting new channels.

The heaviest normal drainage was that in south-central New York, concentrated in the Susquehanna, which cut the gorge south of Sayre, Pa., and the river which drained Lake Iroquois through the Mohawk Valley, the Iromohawk. This great river was the predecessor of the St. Lawrence, which it probably exceeded in volume, as it carried not only the outflow of the glacial Great Lakes, but the copious waters from the glacial melting.

Subglacial Drainage.—This class of glacial streams has been noted chiefly in relation to eskers, which fall under another head in this writing. It is not likely that all eskers were laid down in the beds of streams actually beneath, or in tunnels under, the ice sheet, though some probably were. Probably most subglacial or englacial streams were full loaded with detritus, and it is not likely that many streams beneath the ice margin were so free of drift or under such hydraulic pressure as to seriously erode their beds. However, a few peculiar channels, or "dead" creeks, have been noted which have such form and relations as to suggest erosional flow beneath the stagnant margin of the ice. One of these bayou-like channels is that of Dead creek, a tributary of Seneca River, lying southwest of Baldwinsville, and mapped on the Baldwinsville sheet.

Marginal Drainage.—This class of drainage phenomena included many of the most conspicuous and interesting features connected with the disappearance of the ice sheet, and they have been the subject of much work by the writer. The ice-border drainage channels are important as they locate ice-front positions and determine the altitude of the glacial lakes which they drained. They are humanly, or economically, important since they have graded the ways for many lines of communication or transportation. And they are specially valuable for geologic instruction since they are widely distributed and easily recognized products of long extinct agencies.

It is evident that stream flow along the ice margin could occur only where the land surface sloped toward the ice, and consequently only north of the divide. The remarkable physiography of the western half of the state favored the production of glacial lakes, which required outlet channels for the imprisoned waters.

The most notable series of ice-border drainage channels occur in five districts. (1) On the south slope of the Erie basin, where the ice-impounded waters in the north-sloping valleys escaped westward into the Erian glacial lakes. (2) Along the south slope of the Ontario basin the glacial waters found eastward escape toward the Mohawk-Hudson depression. (3) On the

Helderberg scarp, west of Albany, the waters of the Ontario and Mohawk basins escaped southward into the Hudson marine inlet. (4) In the district about Rome, at the east end of the Ontario basin, the waters from both the north and the west flowed along the sides of the ice lobe to reach the Mohawk Valley. (5) On the north and west sides of the Lowville highland the waters of the southwestern Adirondacks and the Black Valley forced their passage into Lake Iroquois.

The channels leading east through central New York, more conspicuously developed in the Syracuse district, were the predecessors of Niagara River in their function, the equal of Niagara in volume, and the rival of Niagara in cataract phenomena.

The successor of the Iromohawk and the immediate predecessor of the St. Lawrence was the outlet river of the second Lake Iroquois. This flowed across the north point of the Adirondack highland, at Covey Gulf, on the international boundary, with further flow in ice border channels along the slopes northwest of Plattsburg, on the Dannemora and Moors quadrangles.

CONSTRUCTIONAL WORK OF STREAMS.

Subglacial: Eskers.—The singular ridges of gravel, the laggard material in the beds of glacial streams, are well represented in the western part of the state and occur in the eastern part. Those lying in the northwestern section of the state have been studied, but the results are not published. Tarr describes in Folio 169 (pp. 22–23) several which lie in the Susquehanna drainage territory, and of large dimensions, and Carney recognizes nine on the Moravia quadrangle. Eskers may not occur on southward slopes where the glacial streams had steeper gradient and free flow, but in localities where the ice margin was comparatively stagnant and the drainage was sluggish.

The argument for subglacial origin of eskers finds some support in the New York examples. Tarr regards some of those in the Susquehanna district as certainly made by subglacial streams. An esker four miles east of Clayton was deposited about 350 feet beneath the level of Lake Iroquois, which was laving the ice front, and it is difficult to explain how it could have been constructed and its definite ridge-form preserved unless it was built directly on the ground. The same argument applies to the Ingoraham esker, north of Plattsburg.

Extraglacial: Kames.—Isolated mounds of sand or gravel are usually embryo deltas of glacial streams, and are commonly associated with eskers. By linear multiplication they not infrequently grade into esker ridges.

As kames are built at the debouchure of glacial streams, they indicate positions of the ice edge. Areas of kames lie in belts of recessional moraines, and indeed constitute a large part of the New York moraines. The glacial débris which was not spread as the till sheet or rubbed into drumlins was largely gathered up by the drainage and dropped as some form of water-laid drift.

In western New York a few large kame areas are not closely connected or clearly associated with any conspicuous moraine belt, but nevertheless must represent recessional moraine. It is possible that some smaller kames might have been built by land drainage into lateral glacial lakelets, but detritus from land erosion must commonly have produced deltas or sandplains and be easily recognized by form and association. The great development of kames, at least in western New York, is north of the divide, and they were built in the waters of glacial lakes. This association with standing waters is so pronounced

that it gives force to the idea that all typical kames are formed by streams debouching into water bodies, and sometimes by subglacial streams under hydraulic pressure. Streams debouching on the land would naturally produce either outwash plains or valley trains. The fact that basins or kettles, believed to be due to melting out of buried ice blocks, are usually abundant in areas of kames, seems to prove that the materials were laid down in standing water in close association with the stagnant ice margin, either on the ice or in hollows and valleys and reentrants in the ice.

Extraglacial: Outwash Plains.—These are the gravel and sand deposits spread out in front of the glacier by the outflow of the glacial streams and which can not be classed on the one hand as deltas or on the other as valley trains. Water-laid drift in facial contact or close association with the moraines and which can not be distinguished either as delta, kame or valley train, may safely be put in the indefinite class of outwash gravel plains. North of the divide where built in lakes they grade into deltas and kames. South of the divide they constitute most of the valley fillings, especially of the broader valleys which lay athwart the direction of ice flow.

A not uncommon feature of the gravel plains and one which shows the close relation to the glacier front, is the existence of ice-block kettles. The term "pitted plain" has been applied to the sand plains with numerous kettles. Another feature indicating their genesis is the preservation in some cases of the ice-contact slope. The outwash sand and gravel plains are more common in the southwest part of the state and in the Mohawk Valley. In the highlands the drainage was too free and vigorous. In the Champlain-Hudson Valley, lower levels, the sea-level waters distributed the glacial stream detritus, or it was buried under the deluge of sand contributed by the rivers since the ice disappeared. The very extensive sandplains on both sides of the Hudson River and Lake Champlain, for example, the Saratoga district, must be classed as marine deltas. But on the walls of the great valley above the marine plain Woodworth has noted ice-contact slopes of glacial outwash deposits. In the Susquehanna district Tarr found numerous plains of this class.

Extraglacial: Valley-Trains.—South of the divide, where the drainage had free escape, some detrital filling of the valleys is common and occasionally abundant. The high-level flood plains along the valley sides and the elevated deltas of lateral tributaries testify to the glacial floods and their burden of detritus. The deposit by glacial flow is of course intermingled with and in places buried under land stream detritus. The valley trains may be regarded as heading in outwash plains, and one might regard the glacial gravel deposits in the entire length of the valleys north of the terminal moraine as outwash. This view would restrict the true valley-trains to the fillings of valleys beyond the terminal moraine or reach of the ice sheet. In this latter view the valley-train drift would occur in New York only along the south side of Long Island, and in the small area south of the Alleghany River.

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(*To be concluded*)

SCIENTIFIC NOTES AND NEWS

PROFESSOR WILLY WIEN, of Würzburg, will deliver at Columbia University, during the month of April, a series of lectures on recent developments in theoretical physics. Professor Wien received the Nobel prize in physics in 1911 and is well known for his researches in radiation and the electrical constitution of matter.